Overview and Future Directions of DARPA's Advanced Energy Technologies Program

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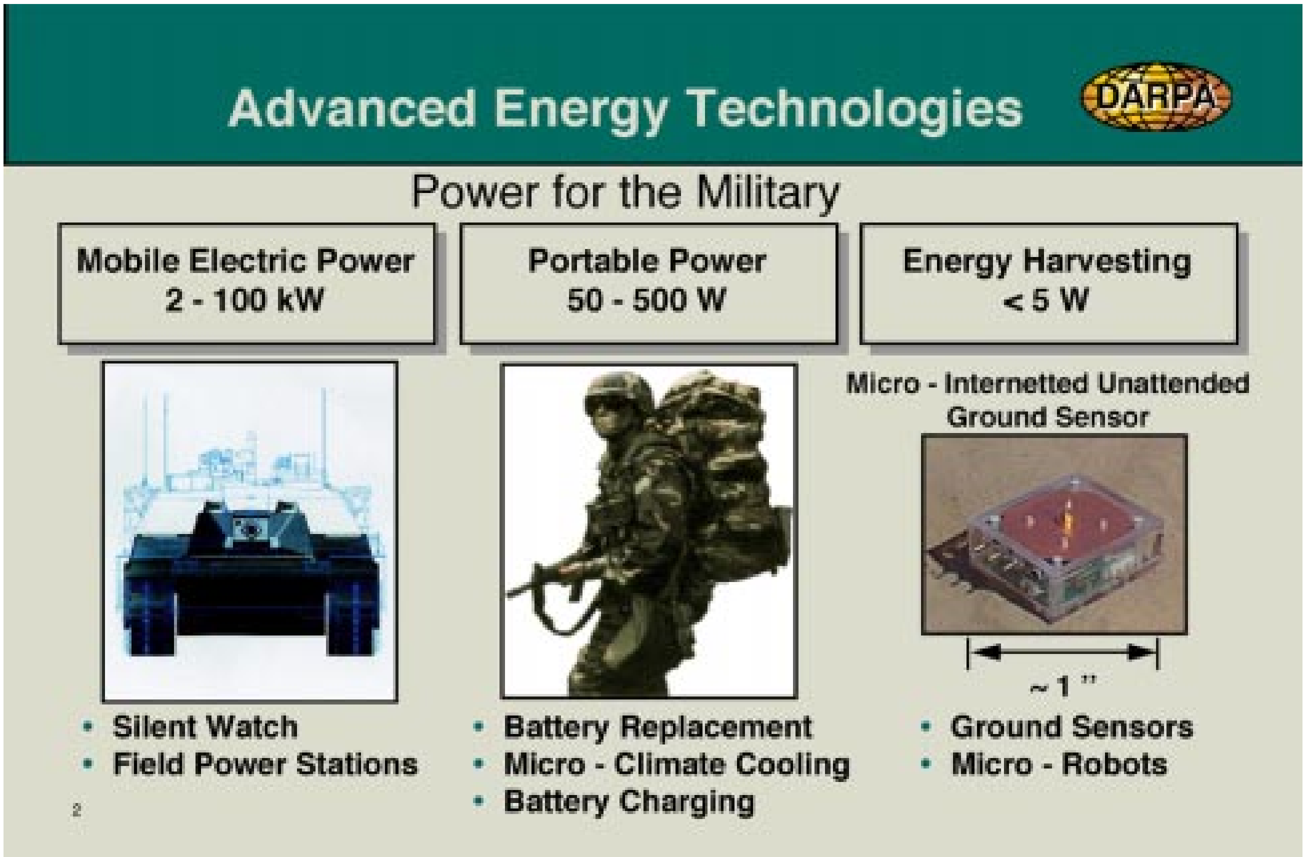
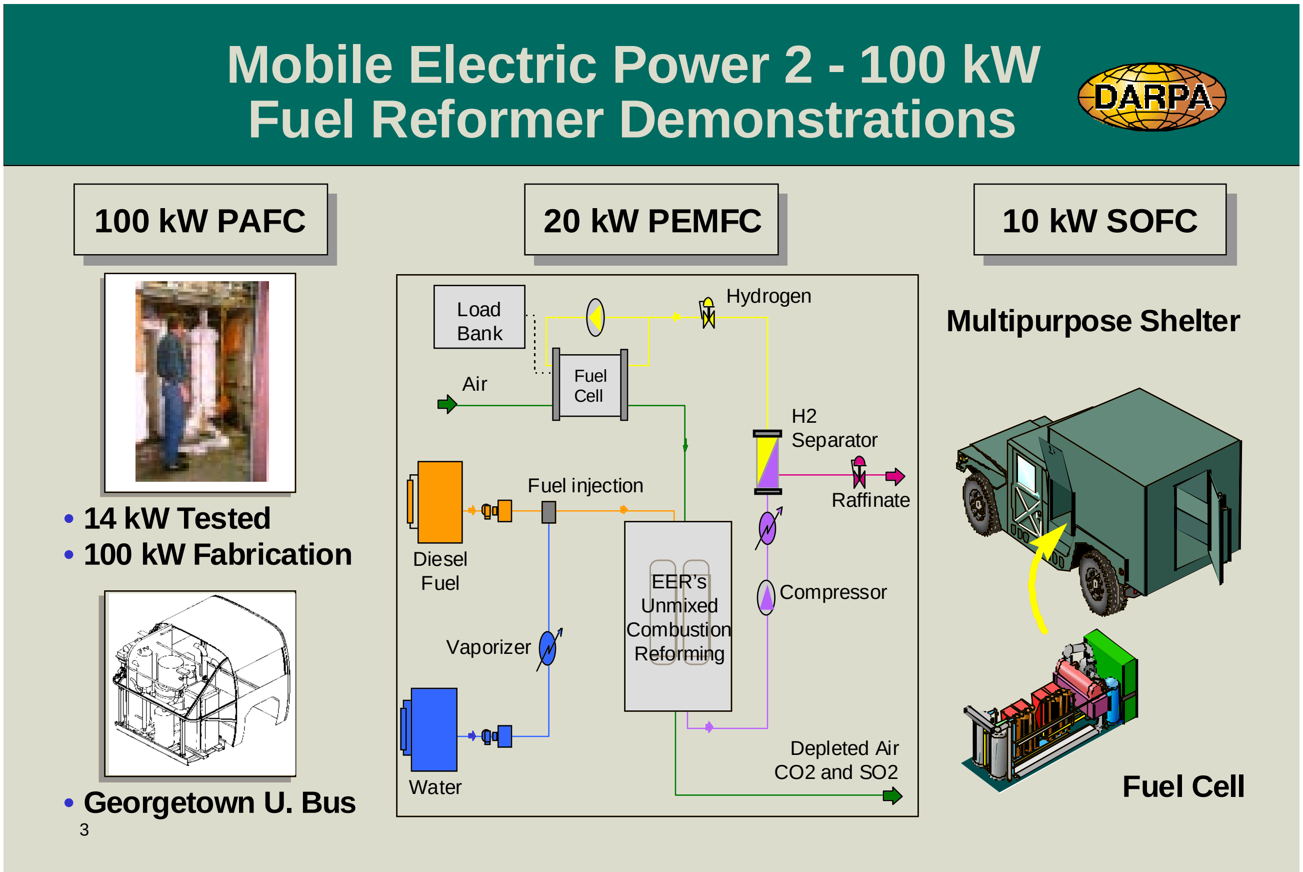


Today’s power sources for the soldier and military platforms are costly and have severe performance limitations including insufficient specific energy and power, unacceptable thermal and acoustic signatures, and cost. DARPA has embarked on an aggressive program to address these issues over a wide range of power levels.

The three major thrust areas, Mobile Electric Power, Portable Power, and Energy Harvesting, are focusing on power sources for platforms or diesel generator set replacements, individual soldier use, and small unattended devices that require low levels of power for long periods of time. Some of the target applications for the DARPA program are given on the slide.

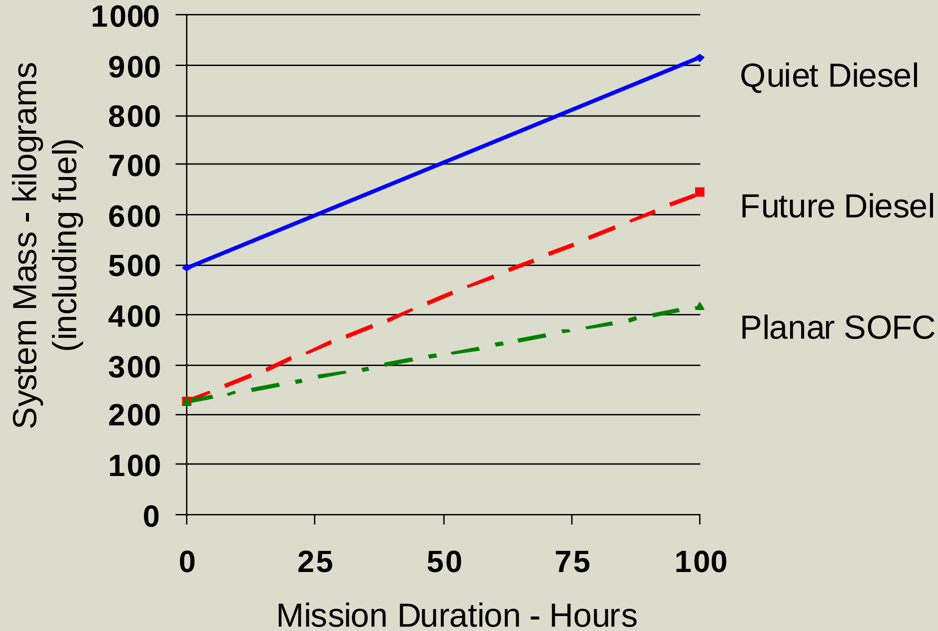
I will discuss the status of these thrust areas and some of the R&D issues that need to be resolved before these technologies can be inserted into military systems.



The Department of Defense procures, maintains, and upgrades a family of mobile field generators and auxiliary power units for use by the various services. These diesel fueled generators have many key areas that need improvement, such as their excessive noise and pollution, relatively low efficiency (especially at part-power, their normal operating point), and frequent maintenance by skilled personnel. The program goal is to develop a fuel cell for military applications operating *directly* on logistics fuel (i.e., DF-2 or JP-8) that are competitive with present diesel generators in weight and volume, and demonstrate the inherent fuel cell characteristics of low maintenance, high reliability, low noise, negligible emissions, and high efficiency over a wide power range. The major thrust of the program has been to develop compact fuel reformers that can convert logistics fuels into a fuel that is acceptable to a fuel cell, i.e., hydrogen. In addition, planar solid oxide fuel cell technology has been supported as it offers the advantage of a closer thermal match to reformer technologies and potentially the highest specific power of any fuel cell technology.

R&D efforts in Mobile Electric Power are culminating in three demonstrations: 1) a 100 kW adiabatic reformer will be integrated with the phosphoric acid fuel cell being built for the Georgetown University bus program; 2) a 20 kW unmixed reformer will be integrated with a proton exchange membrane fuel cell; and 3) a 10 kW partial oxidation reformer will be integrated with a planar solid oxide fuel cell stack.

System Mass vs. Mission Duration
Mobile Electric Power - 10 kW (Logistics Fuel)



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This graph compares the total system mass, including fuel for diesel generator technology compared to fuel cell technology for a 10 kW system operating for up to 100 hours. Clearly, the planar solid oxide fuel cell technology provides a much lighter system. Additional benefits include low acoustic signature and lower emissions. However, rapid start up and system endurance are still unresolved issues with this technology.

Mobile Electric Power - Opportunities

Fuel Reforming

- Size
- Efficiency
- Sulfur Removal and/or Tolerance
- Hydrogen Purity
- Fuel Cell Integration

Customize for the Military

- System Size and Weight
- System Efficiency
- Environmental Issues
  - shock, vibration, temperature, altitude, salt spray, dust, etc.
- Signature
  - acoustic, thermal, etc.
- Operation and Maintenance

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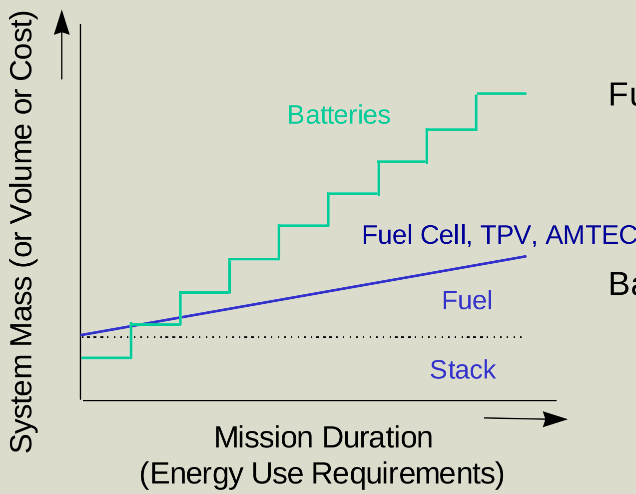
While the Mobile Electric Power demonstrations are encouraging, many issues need to be resolved before these technologies can be inserted into military systems. The results of demonstrations of integrated fuel reformer/fuel cell systems will provide the military with data which can be used to evaluate the best target applications for the various technology options. In addition to the design and performance issues, attention must be paid to the military environment and the ease of operating and maintaining these systems. Opportunities for follow-on programs in the services are likely in the future as the advantages of these systems are demonstrated.

Energy Conversion vs. Energy Storage



Energy Density of Selected Fuels and Batteries

Fuel:	Energy Density
Diesel Fuel/Jet Fuel	12,000 Wh/kg
Methanol	5,000
High Explosive	1,000
Battery:	
Primary Battery (est. max.)	500
Rechargeable (est. max.)	200
Li/SO_2 Battery (primary)	176
Alkaline Battery (primary)	80
Nickel-Cadmium (secondary)	40

Driving Force: Substantially decreased size, weight, and cost with improved safety and environmental compliance → Increased force mobility

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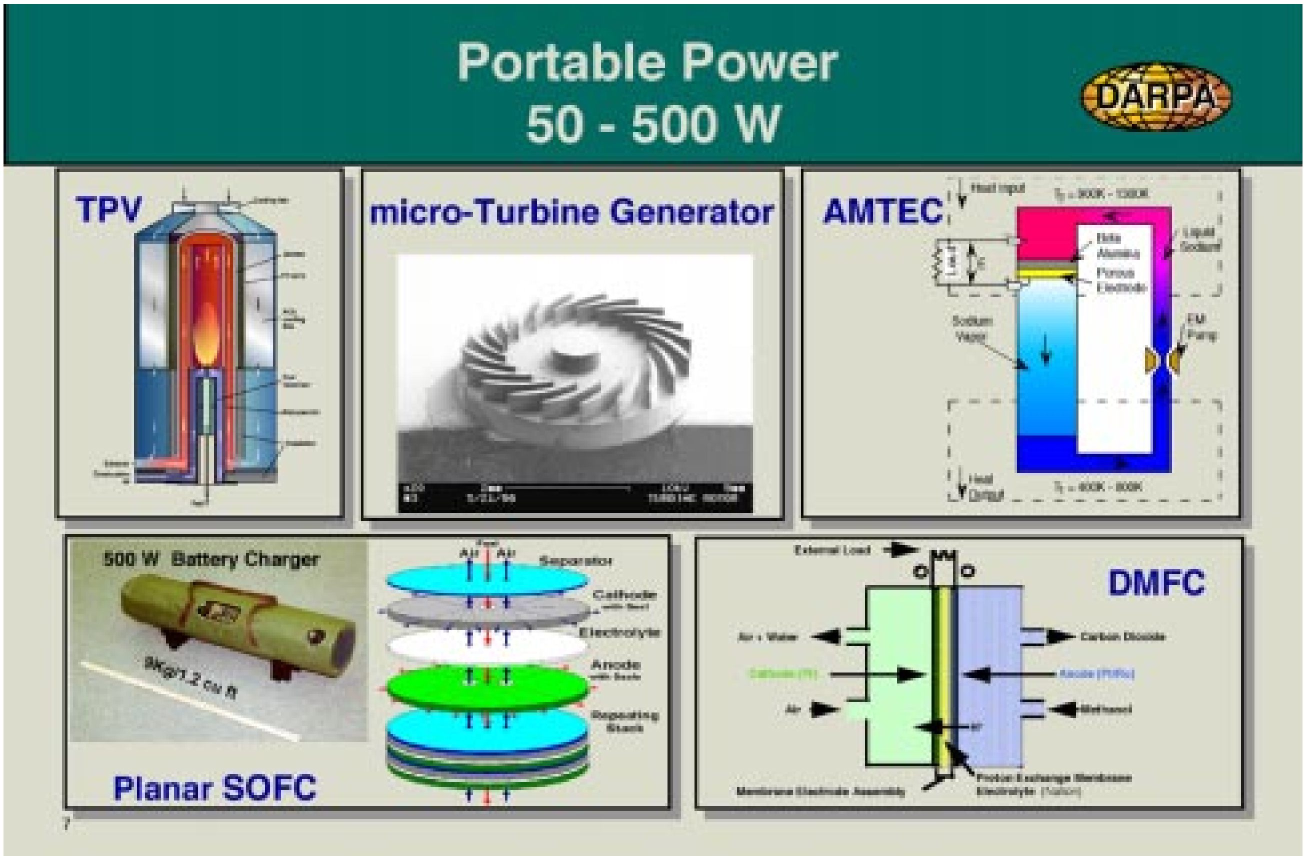
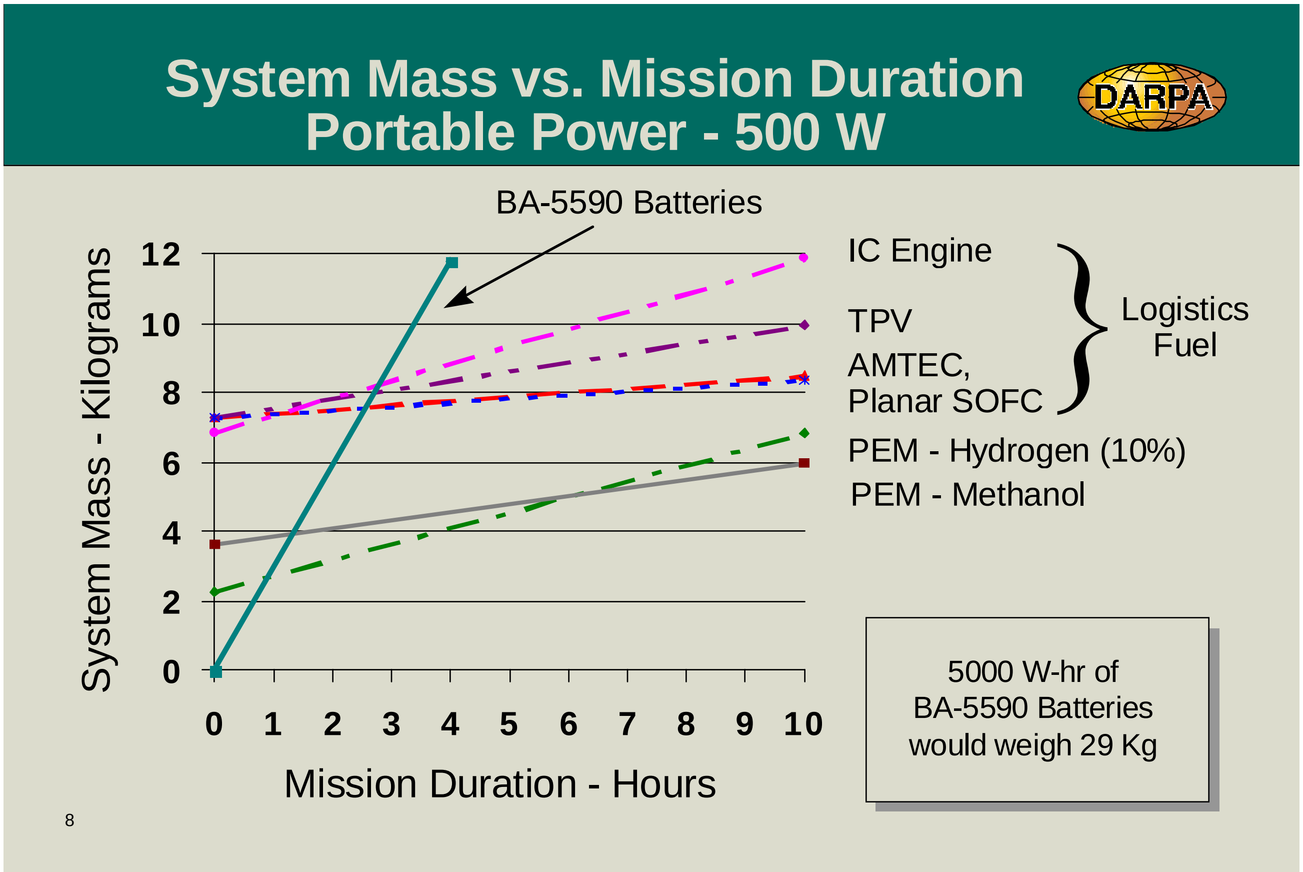
Batteries are the power source of choice for short missions, but as power demands and mission times increase, energy conversion (vs. energy storage) is preferable. For very long missions, the specific energy of the system approaches the theoretical specific energy of the fuel because the energy conversion device becomes a small fraction of the total weight and volume.



The demand for portable power for the military continues to increase and cannot be met by primary batteries due to their prohibitive weight and cost. If rechargeable batteries are used, battery chargers will be needed. The DARPA portable power thrust seeks to develop power sources in the 50-500 W range for battery replacements, micro-climate cooling applications and battery charging. These concepts are based on easily handled liquid fuels. For the larger systems, i.e., 500 W, logistics fuel is preferred. In addition to being readily available, diesel fuel offers very high theoretical energy densities (13.2 Wh/g). Thermophotovoltaic (TPV), Alkali Metal Thermoelectric Converter (AMTEC), and Planar Solid Oxide Fuel Cell (SOFC) technologies are being developed for the battery charging application. Methanol has a much lower theoretical energy density (5.6 Wh/g), but when used in a direct methanol fuel cell, it compares favorably to diesel from a system perspective.



This graph compares the total system mass, including fuel, for a 500 W system operating up to 10 hours. These lines represent aggressive program goals for the DARPA supported technologies but have not yet been achieved. It is clear that all of the technologies in the portable power thrust will exceed the performance of the IC engine. In addition, these technologies have few moving parts, and therefore it is expected that maintenance will be significantly less than the IC engine. It is significant to note that if the same mission (10 hours at 500 W) were to be performed with batteries, the system weight would be almost five times that of the direct methanol fuel cell.

Portable Power - Opportunities

Batteries - significant improvements over existing systems

>> 2X Specific Energy/Power

Fuel Cells

- Direct Methanol Oxidation
  - Methanol Crossover
  - Cathode Catalyst Activity and Methanol Tolerance
  - Anode Catalyst Activity
  - Membrane Electrode Assembly Processing
- Alternative Fuel Options and Concepts

TPV and AMTEC

- Low Cost and Efficient PV Cells
- Efficient TPV Cavity Designs
- Compact AMTEC Designs
- Efficient Fuel Combustion at Low Flow Rates
- High Temperature Heat Recuperation

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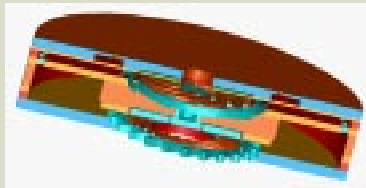
Many unresolved issues exist in order to reach the goals that were graphically displayed on the last slide. Some of these issues and research and development opportunities are listed here.

MIT Micro Turbine Generator Performance Comparison



	μ Turbogen*	BA-5590 ($LiSO_2$) Battery
Power Output	50 W	50 W
Energy Content	175 W hr	175 W hr
Weight	50 g	1100 g
Volume	50 cc	880 cc
Specific Energy	3500 W hr/kg	175 W hr/kg
Energy Density	3 W hr/cc	0.2 W hr/cc

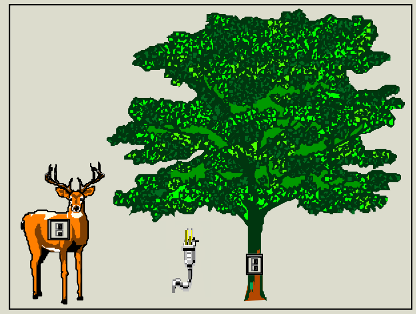
10 * Effort lead by MIT; all values include fuel

Under a MURI program with the Army Research Office and with additional support from DARPA, MIT is developing a micro-turbine generator based on a lithographically defined manufacturing process. If successful, this device will have performance characteristics far exceeding any portable power source today. Figures of merit are compared for the microturbine generator and a conventional primary lithium battery. The specific energy is 20 times that of the battery and the specific power for this device is equivalent to large scale jet engines. Many challenges exist to make this concept a reality. Thus far, components have been manufactured from silicon. It will be necessary to make these components out of more refractory materials, e.g., silicon carbide, sapphire, for this device to function as a micro-turbine generator. However, silicon-based structures could be used for other devices, e.g., compressors, and this is under investigation.

Energy from the Environment

Marine Corps
Solar - PV; Wind
6 kW

DARPA CIS
Flexible PV
18 W



DARPA Energy Harvesting
Bio, Mechanical, Gradients,
Solar, Transmission Line,
EM, Human Activity, etc.
< 5 W

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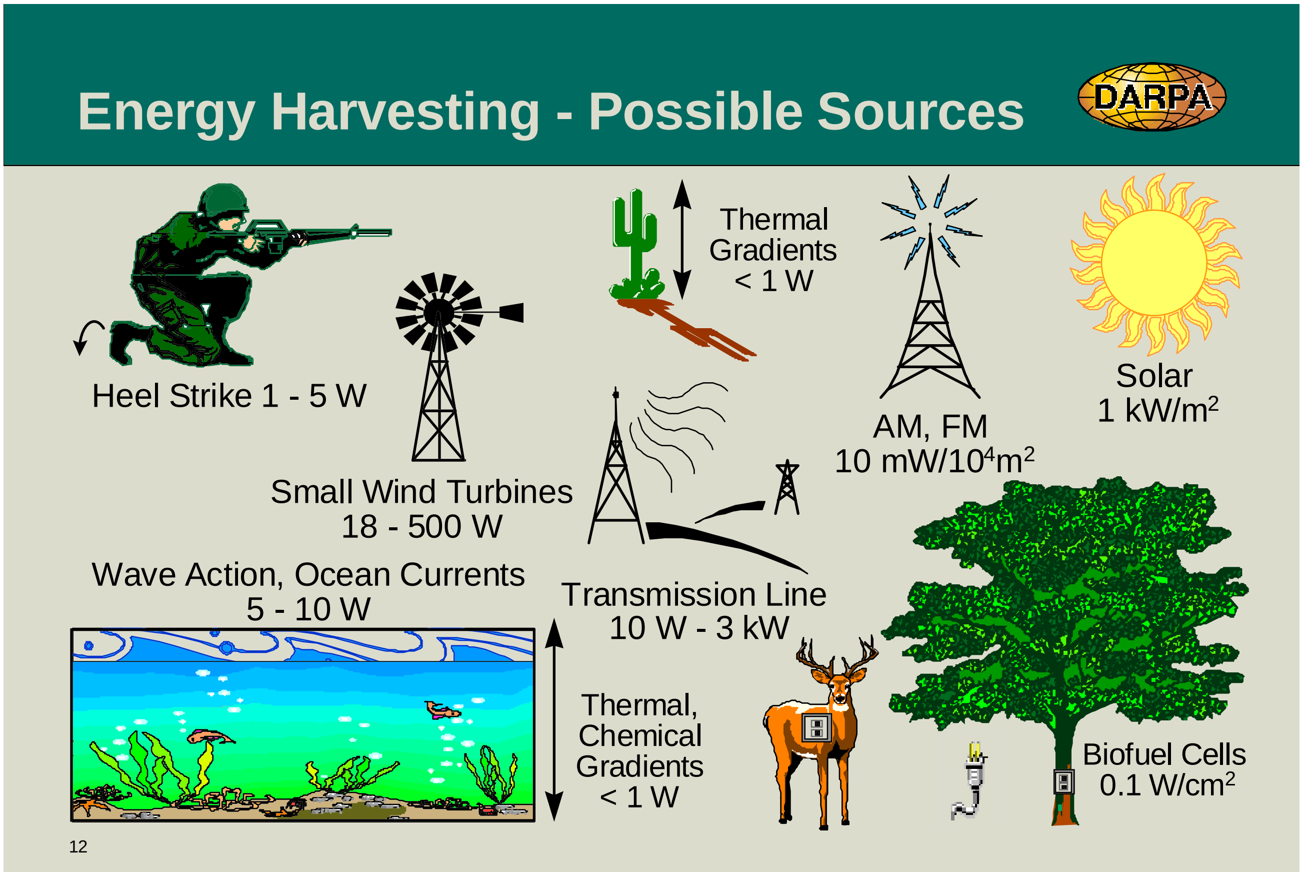
One approach to solving the energy problem for the military is to exploit ambient sources of energy. The Marine Corps has been testing a 6 kW system based on rigid solar panels and wind power. DARPA has a program to manufacture copper indium diselenide photovoltaic material on flexible substrates for use in the field. Shown is a battery charging application; in this case, silicon is the PV material. A new opportunity at DARPA is Energy Harvesting. Shown is a cartoon depicting a tree or animal as a fuel source for a biofuel cell. The DARPA program will focus on low-profile, low-power systems on the order of 5 W or less that will operate indefinitely.



There are many sources of energy or fuel that can be harvested for continuous or deferred use. Some of these are shown on this slide.

Energy Harvesting: A Commercial Example

Keys to success

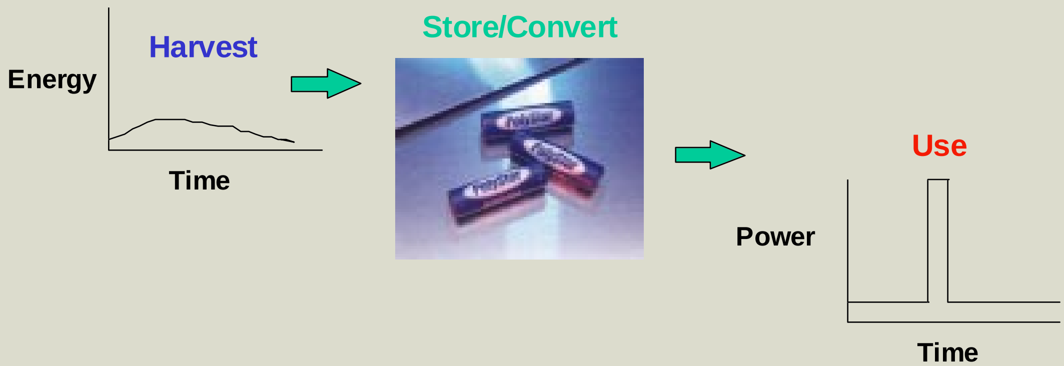
- Mechanical-to-electrical conversion
- Efficient energy storage
- Low power application

A commercial watch has been developed that embodies the principle that the DARPA program is interested in for military use. This watch is a sophisticated collection of integrated components that captures kinetic energy, stores and conditions it and uses it to keep time and drive the hands. Careful engineering and matching of the energy source to the duty cycle of the device is a key to successfully exploiting low power level environments.

Energy Harvesting - Opportunities

DARPA

- Harvesting Concepts - On and Off the Soldier
- Compatible Storage and Conditioning
- Power Management vs. Duty Cycle
- Materials/Fuels Processing
- Size, Weight (Footprint)



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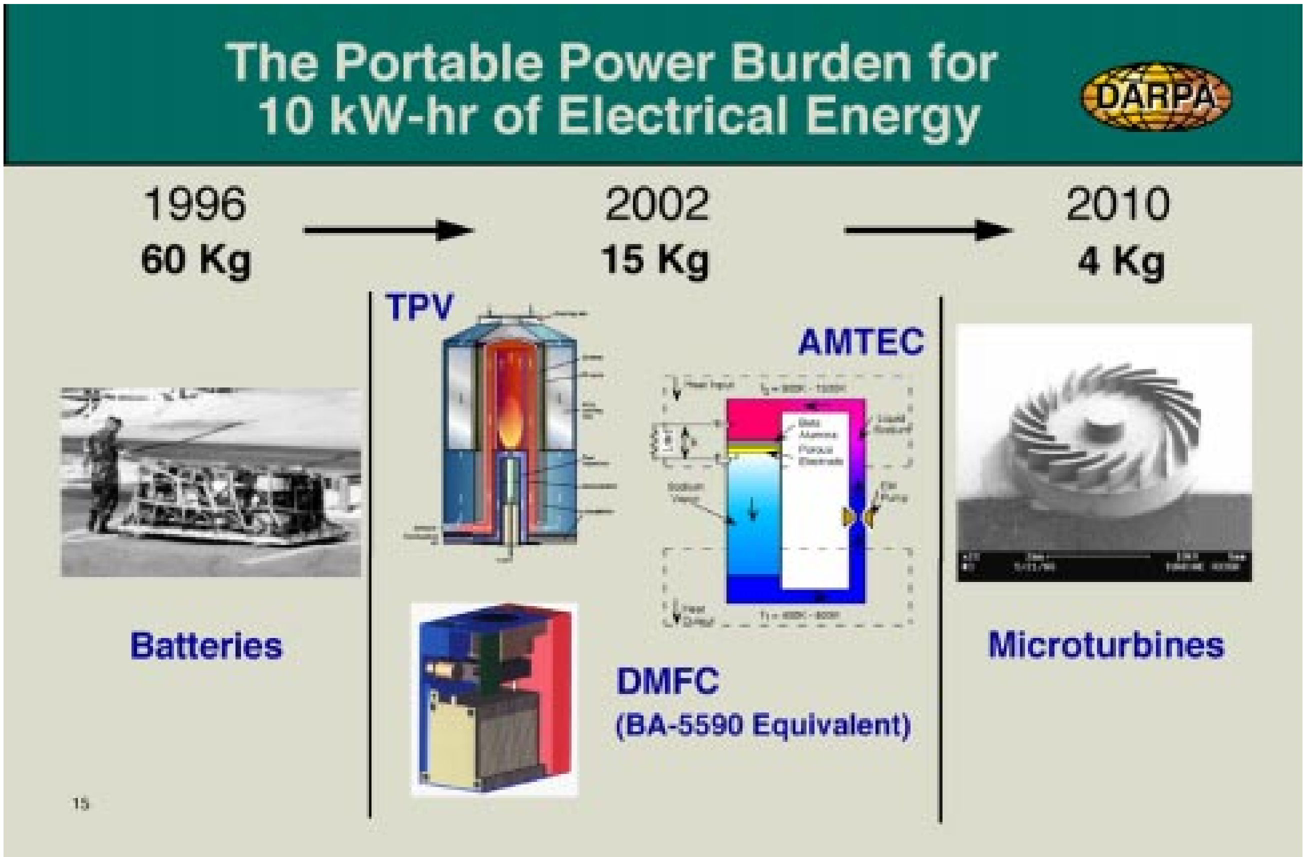
These are some of the broad issues that need to be addressed in the Energy Harvesting program. DARPA is interested in any new concepts that you may have that will provide the military with “perpetual” power in the < 5 W range. As the ambient sources of energy are not particularly intense, it is necessary to carefully consider an application and its duty cycle and create an integrated system as has been done in the commercial watch example above.



While batteries have served the military well, and will continue to do so, advanced energy technologies will offer significantly more capability for less cost in the future. As we look forward to 2000 and beyond, it is hoped that we can make a 10X improvement in performance of our power systems by pursuing an aggressive R&D program and pushing new technologies forward. The Advanced Energy Technologies Program welcomes new ideas to meet the energy and power demands of the 21st century military.